AD-A010 631

EMP EVALUATION OF JUNCTION BOXES, JUNCTION-BOX COVERS, AND GASKETS

D. J. Leverenz, et al

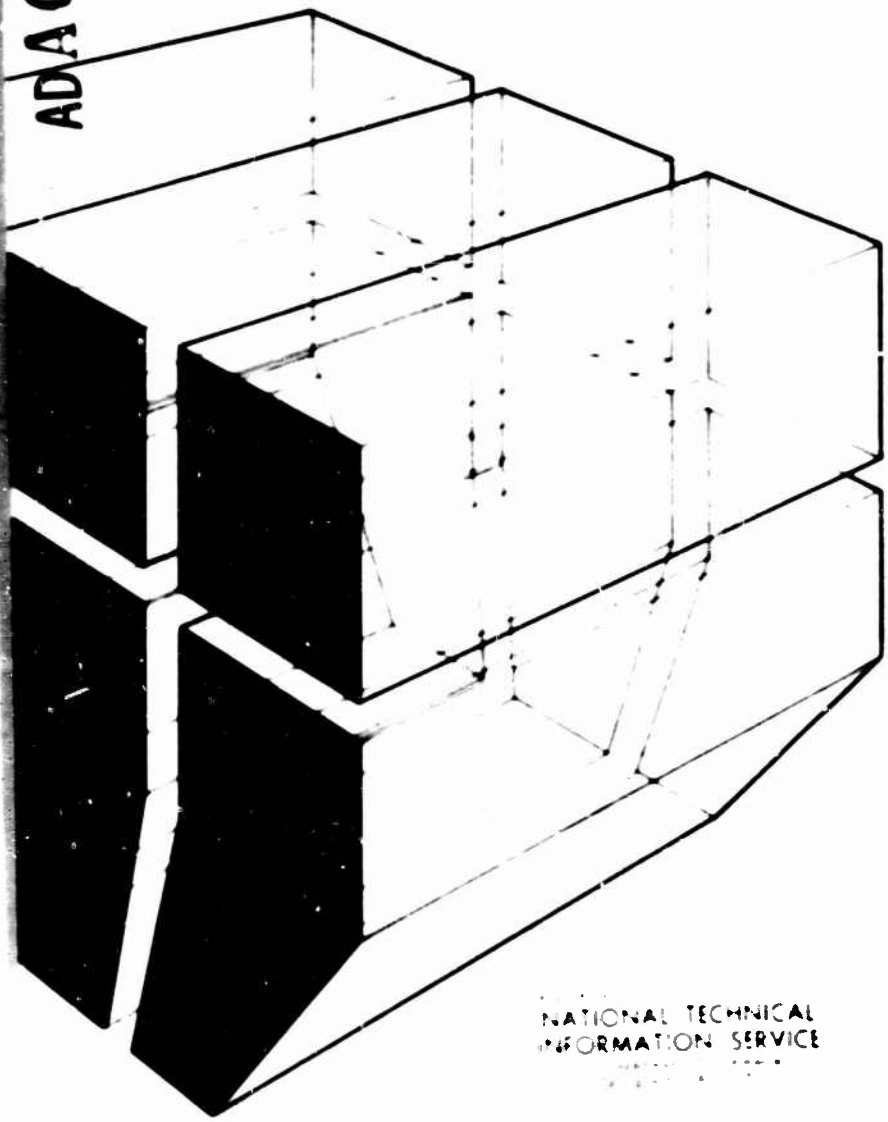
Army Construction Engineering Research Laboratory
Champaign, Illinois

May 1975

construction
engineering
research
laboratory

TECHNICAL REPORT C-18
May 1975

EMP EVALUATION OF JUNCTION BOXES, JUNCTION-BOX COVERS, AND GASKETS



by
D. J. Leverenz
R. G. McCormack
P. H. Nielsen

CERL

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: CERL-TR-C-18	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): EMP EVALUATION OF JUNCTION BOXES, JUNCTION-BOX COVERS, AND GASKETS	5. TYPE OF REPORT & PERIOD COVERED: FINAL REPORT
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): D. J. Leverenz, R. G. McCormack, P. H. Nielsen	8. CONTRACT OR GRANT NUMBER(s): IAO 72-20
9. PERFORMING ORGANIZATION NAME AND ADDRESS: CONSTRUCTION ENGINEERING RESEARCH LABORATORY, P.O. Box 4005, Champaign, IL 61820	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: May 1975
	13. NUMBER OF PAGES: 53
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

junction box
electromagnetic radiation
gasket

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study reports test results from RFI testing of electrical junction boxes with bolt-on covers. A number of cover-gasket configurations were tested. Tests indicate that a large improvement in the shielding effectiveness of junction boxes can be obtained by increasing the number of cover bolts or using a Metex "combo strip" gasket. A simple field fix that provides a large increase in shielding effectiveness can be made by doubling the number of cover bolts used on the junction boxes.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This investigation was conducted for the U. S. Army Engineering Division, Huntsville, (HND), under IAO 72-20, dated 2 August 1971 and including subsequent change orders. The work was performed by the Electro-Mechanical Branch, Facilities Engineering and Construction Division (FE), Construction Engineering Research Laboratory (CERL).

Appreciation is expressed to M. J. Pollock for his guidance and to M. Hill and J. Simon, all of CERL, for their assistance in this investigation. The contributions of F. Smith of HND are also acknowledged.

COL M. D. Remus is the Commander and Director of CERL and Dr. L. R. Shaffer is the Deputy Director. Mr. E. A. Lotz is the Chief of FE.

CONTENTS

	DD FORM 1473	1
	FOREWORD	3
	LIST OF FIGURES AND TABLES	5
1	INTRODUCTION	9
	Background	
	Scope	
2	TEST PROCEDURES	10
	Introduction	
	Test Samples	
	Measuring Techniques	
3	INSTRUMENTATION	25
	Shielded Enclosure	
	CW Test Equipment	
	Pulse-Test Equipment	
4	TEST RESULTS	32
	CW Tests	
	Pulse Tests	
5	SUMMARY	36
	Conclusions	
	Recommendations	
	APPENDIX A: Data Obtained During CW Tests of the Small, All-welded, 11-Gauge Steel Junction Box	38
	APPENDIX B: Data Obtained During CW Tests of the Large, All-welded, 11-gauge Steel Junction Box	41
	APPENDIX C: Data Obtained During CW Tests of the Spot-Welded, 16-Gauge Steel Junction Box	51
	REFERENCES	53
	DISTRIBUTION	

FIGURES

Number		Page
1	Small All-Welded Junction-Box CW Test Fixture	11
2	Small All-Welded Junction-Box Covers (Left, with RFI Gasket Material; Right, with Rubber Gasket) as Received from SAFEGUARD Site	11
3	Metex "Combo Strip" RFI Gasket Installed on Junction-Box Test Fixture	13
4	Flat Plate Cover Installed on Junction-Box Test Fixture	13
5	Close-up of Corner of Flat Plate Cover Installed on Junction-Box Test Fixture	14
6	Wrap-Around Cover Installed on Test Fixture	14
7	Eccoshield Aluminum-Foil Tape on Junction-Box Cover	16
8	Eccoshield Aluminum-Foil Tape on Junction-Box Cover Showing Tape Wrapped Around Edge	16
9	Flat Cover with Channel Iron Pressure Plates Mounted on Shielded Room Wall	17
10	Bottom of Spot-Welded Junction Box Mounted on Shielded Enclosure (without Conductive Tape)	18
11	Bottom of Spot-Welded Junction Box (with Conductive Tape)	18
12	Technit Gasket Installed on Junction Box	20
13	Junction Box with Copper Braid in Parallel	20
14	Junction Box with Two Copper Braids in Parallel	21
15	Junction Box with Doubled Number of Cover Bolts	21
16	Test Setup for CW Testing of Junction Boxes	22
17	Correction Factor for Low Signal Levels During CW Tests	24
18	Test Setup for Injected Current Pulse Testing of Junction Boxes	26
19	Spot-Welded Junction Box Installed in Parallel Conduit Transmission Line (Box Vertical)	27

FIGURES (cont'd)

Number		Page
20	Spot-Welded Junction Box Installed in Parallel Conduit Transmission Line (Box Horizontal)	27
21	Transmitting Equipment--10 kHz and 40 kHz	29
22	Transmitting Equipment--200 kHz, 1 MHz, and 30 MHz	29
23	Transmitting Equipment--500 kHz and 2.5 GHz	30
24	Receiving Equipment	30

TABLES

1	Summary of CW Test Results--Small All-Welded 11-Gauge Steel Junction Box	33
2	Summary of CW Test Results--Large All-Welded 11-Gauge Steel Junction Box	34
3	Summary of CW Test Results	35
4	Pulse Test Results--Spot-Welded 16-Gauge Steel Junction Box	36
A1	Test Data for Junction Box with No Cover (#1)	38
A2	Test Data for Junction Box with No Cover (#2)	38
A3	Test Data for Junction Box with Factory - Supplied Rubber Gasket	39
A4	Test Data for Junction Box with No Gasket	39
A5	Test Data for Junction Box with Steel-Wool Gasket	40
A6	Test Data for Junction Box with Elastomet Gasket	40
B1	Test Data for Junction Box with Flat Plate Cover--No Gasket (#1)	41
B2	Test Data for Junction Box with Flat Plate Cover--No Gasket (#2)	41

TABLES (cont'd)

Number		Page
B3	Test Data for Junction Box with Flat Plate Cover--No Gasket (#3)	42
B4	Test Data for Junction Box with Flat Plate Cover with Chomerics Gasket	42
B5	Test Data for Junction Box with Flat Plate Cover with Metex Gasket (#1)	43
B6	Test Data for Junction Box with Flat Plate Cover with Metex Gasket (#2)	43
B7	Test Data for Junction Box with Flat Plate Cover with Eccoshield PST-C-A Tape	44
B8	Test Data for Junction Box with Flat Plate Cover with Metex Gasket and Eccoshield Tape	44
B9	Test Data for Junction Box with Flat Plate Cover with 1 1/2-In. Channel Iron Stiffners	45
B10	Test Data for Junction Box with Flat Plate Cover with 1 1/2-In. Channel Iron Stiffners and Metex Gasket	45
B11	Test Data for Junction Box with Flat Plate Cover with Paint on Mating Surface	46
B12	Test Data for Junction Box with Flat Plate Cover with Metex Gasket and Paint on Mating Surfaces	46
B13	Test Data for Junction Box with Tight-Fit, Wrap-Around Cover--No Gasket (#1)	47
B14	Test Data for Junction Box with Tight-Fit, Wrap-Around Cover--No Gasket (#2)	47
B15	Test Data for Junction Box with Tight-Fit, Wrap-Around Cover with Metex Gasket (#1)	48
B16	Test Data for Junction Box with Tight-Fit, Wrap-Around Cover with Metex Gasket (#2)	48
B17	Test Data for Junction Box with Loose-Fit, Wrap-Around Cover--No Gasket	49

TABLES (cont'd)

Number		Page
B18	Test Data for Junction Box witn Flat Plate Cover with 48 Bolts	49
B19	Test Data for Junction Box with Flat Plate Cover with 48 Bolts and Metex Gasket	50
C1	Test Data for Junction Box with Cover Removed	51
C2	Test Data for Junction Box with Cover Installed	51
C3	Test Data for Junction Box without Aluminum-Foil Tape	52
C4	Test Data for Junction Box with Aluminum-Foil Tape	52

EMP EVALUATION OF JUNCTION BOXES, JUNCTION-BOX COVERS, AND GASKETS

1 INTRODUCTION

Background. SAFEGUARD Ballistic Missile Defense (BMD) sites have been designed to have a high degree of hardness against the effects of various types of electromagnetic radiation resulting from nuclear attacks or BMD-site operation. As part of the hardness of design, steel conduit and junction boxes are used to provide shielding for signal, communication, and power cables for both intersite and intrasite connections. It was found, however, that several of the steel junction boxes, which had been installed where exposure to electromagnetic radiation was likely under certain conditions, did not provide adequate shielding.

HND was responsible for modifying these boxes and requested that CERL develop a method of improving the shielding effectiveness of the welded steel junction boxes (both all-welded and spot-welded) with bolt-on lids. It was further requested that, if possible, the improvements be accomplished without a major redesign of the junction boxes, so that the boxes already installed would not have to be replaced.

Evaluations of the various modifications were made using techniques based on those suggested in MIL-STD-285 and IEEE Standard 299,[1] plus some injected current pulse tests. The tests were conducted at CERL by the Facilities Engineering and Construction Division. The results of this investigation are presented herein.

Scope. Tests were conducted on both all-welded and spot-welded junction boxes. A small and a large all-welded junction box were tested--the small box had a cover that measured 6 in. by 6 in. and the large box cover measured 12 in. by 36 in. With the all-welded junction boxes, only the cover seam provided a point of leakage; testing of these boxes was performed by cutting the top 1 in. off and welding it over an appropriate size hole in a steel test panel. The test panels were designed to be mounted on the access port in the wall of a shielded enclosure.

Two test panels were made for the spot-welded junction box (12-in. by 18-in. cover)--for both the box itself and the cover. One panel

[illegible] [illegible], IEEE Standard 299 (Institute of Electrical and Electronics Engineers, Inc., 1969); [illegible] [illegible], MIL-STD-285 (Department of Defense, June 1956).

contained the top 3 in. of the junction box while the other contained the remaining bottom of the box. Again, test panels were designed to mount on the access port of the shielded enclosure.

Injected current pulse tests were also conducted on a 12-in. by 18-in. by 4 1/4-in. spot-welded junction box. This box was mounted on a transmission line that was driven by a current-pulse source. The current picked up by a sense wire inside the junction box was monitored to determine its shielding effectiveness.

For the test samples, various combinations of covers and gaskets were tested. Chapter 2 describes the test samples and the method of testing.

2 TEST PROCEDURES

Introduction. Four junction-box samples were tested during this program using two test techniques and various covers and gaskets. The four samples included a small (6-in. by 6-in.) all-welded junction box for CW testing, a large (12-in. by 36-in.) all-welded junction box for CW testing, a spot-welded (12-in. by 18-in.) junction box for CW testing, and a spot-welded (12-in. by 18-in. by 4 1/4-in.) junction box for injected current pulse testing.

Test Samples. A small (approximately 6-in. by 6-in.) all-welded, 11-gauge steel junction box with a bolt-on cover was tested with and without various gasket materials. The junction box used was obtained from the SAFEGUARD construction site and had a flat plate cover that was bolted to the mounting flange on the box, using six 1/4-in. diameter, 20 thread/in., 1/2-in. length, oval-head brass screws.

The surface of the mounting flange had been ground down, apparently to remove the rough surface that remained after the flange was welded in place. The resulting surface, however, was not level. The greatest surface level variation, as measured with a feeler gauge and a straight edge, was approximately 0.04 in. in a horizontal distance of 2 in.

For test purposes, a fixture was constructed by sawing the top 1 in. from the junction box and welding it to an 11-gauge steel plate after an appropriate size hole had been cut in the plate. The resulting fixture is shown in Figure 1. This fixture was then mounted to a shielded enclosure. The cover and the gasket materials were then installed on the test fixture as they would be installed on a junction box in the field.

The junction-box covers (Figure 2) had also been fabricated from 11-gauge, commercial grade, low-carbon steel (ATSM A36). The covers were approximately 6 in. by 6 in. The junction box also measured

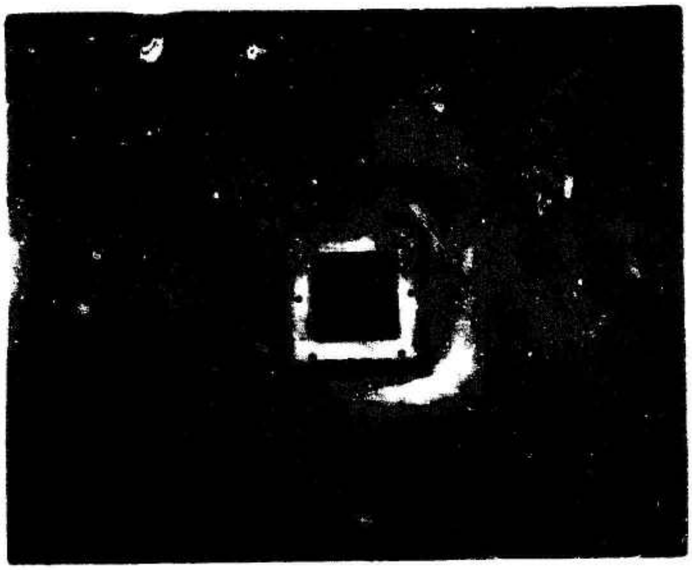


Figure 1. Small all-welded junction-box CW test fixture.

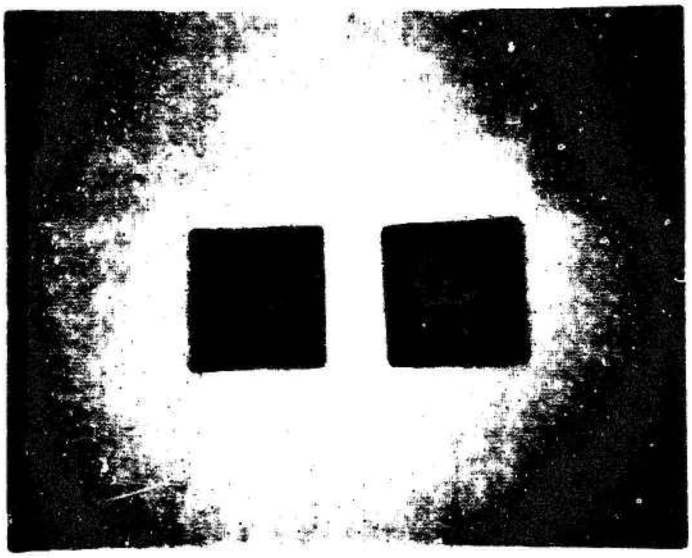


Figure 2. Small all-welded junction-box covers (left with RFI gasket material; right with rubber gasket) as received from SAFEGUARD site.

approximately 6 in. by 6 in. on the outside with a 1-in. flange, leaving an opening of approximately 4 in. by 4 in.

The following gasket materials were tested using the small junction-box test fixture:

a. A nonconductive rubber gasket which was supplied with the junction box by the manufacturer.

b. A steel-wool gasket (a hand-formed continuous pad--approximately 1/4-in. thick before being compressed).

c. A Technit* Elastomet, EMI/RFI shielding gasket with 900 convoluted wires/sq in. embedded in nonconductive silicon rubber, so that wires extend beyond the surface of opposite sides of material.

d. A Metex-Xecon** RFI gasket material consisting of a silver filler in a silicon-rubber base (the material used was 0.060 in. thick).

With the Metex-Xecon gasket, tests were performed using two widths--the width of the flange and a width of 1/8 in. (to simulate narrow-lipped fixtures).

In addition to the small junction box, tests were also performed on a large (approximately 36 in. by 12 in.) all-welded, 11-gauge steel junction box using various gaskets and bolt-on steel covers. An actual junction box of this size was not available; a test junction box was constructed by taking a steel test panel with a 12-in. by 36-in. rectangular hole and welding a mating surface around this hole similar to the mating surface on the small junction box (Figure 3). The mating surface was raised 1 in. above the surface of the test panel, and had 24 1/4-in. diameter, 20 thread/in. holes located around the perimeter with a spacing of 4 in. between bolt holes. This test panel was designed to be installed on the access port of a shielded enclosure. Gasket materials and several types of covers were then installed on the test panel just as they would be installed on a junction box in the field. The covers were attached using case-hardened 1/4-in. diameter, 20 thread/in., 2-in. length, hexagon-head, steel cap screws.

Three types of covers were tested. One was a flat plate cover similar to the one supplied with the small junction box (Figures 4 and 5). The other two were wrap-around covers (Figure 6), which had sides that came down along the sides of the junction box. One of the wrap-around covers made a tight fit with the junction box; the other formed a loose fit.

---

* Marketed by Technical Wire Products, Inc., Cranford, NJ.
** Marketed by Metex Corp., Edison, NJ.

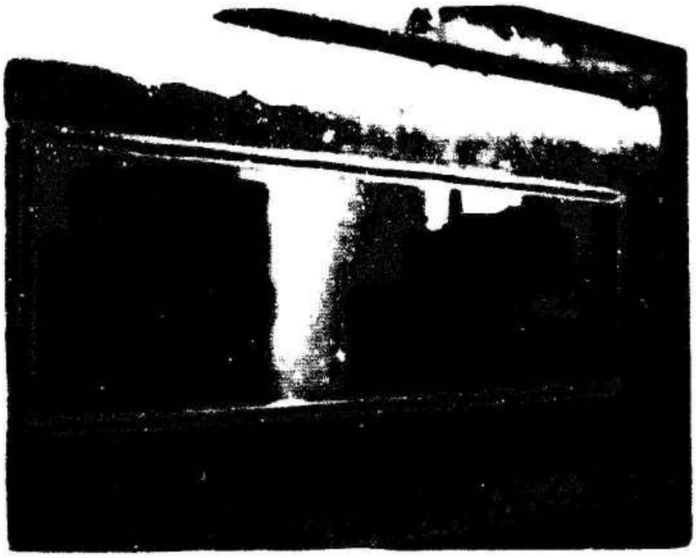


Figure 3. Metex "combo strip" RFI gasket installed on junction-box test fixture.

Figure 4. Flat plate cover installed on junction-box test fixture.

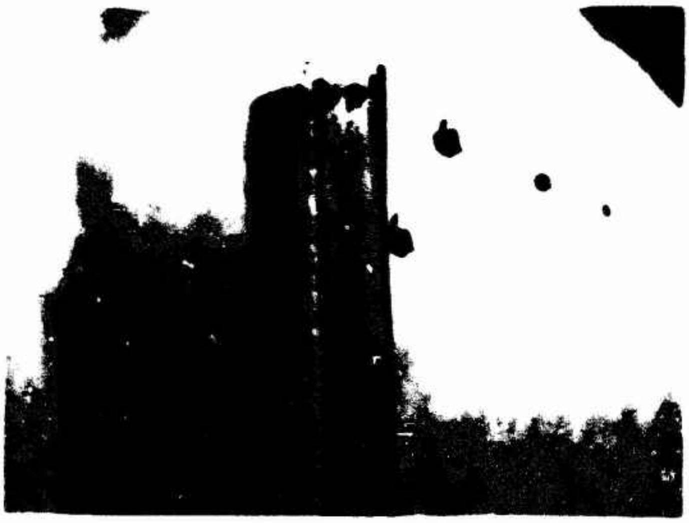


Figure 5. Close-up of corner of flat plate cover installed on junction-box test fixture.

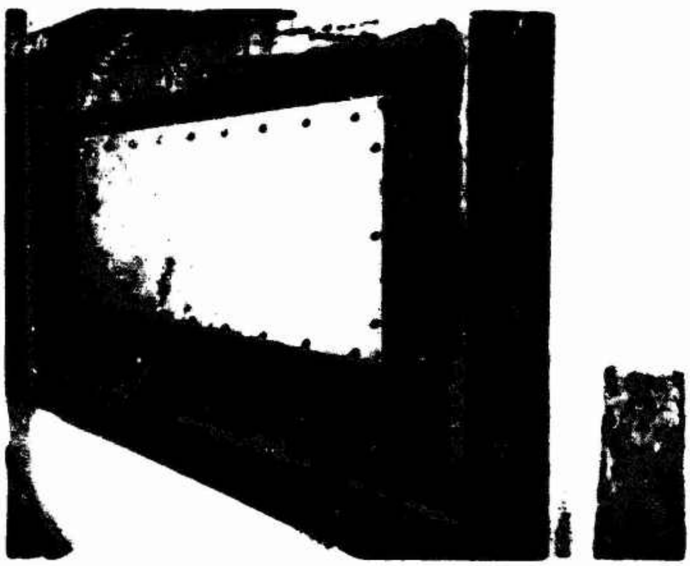


Figure 6. Wrap-around cover installed on test fixture.

The test panel and the covers were fabricated from 11-gauge, commercial grade, low-carbon steel (ASTM A36). The dimensions of the panel-mounted junction box and the various covers were:

Panel-mounted junction box	36 1/32-in. by 12 in. (with 1-in mating lip around the perimeter)
Flat plate cover	36 1/2 in. by 12 in.
Tight-fit, wrap-around cover*	36 1/16 in. by 12 1/32 in.
Loose-fit, wrap-around cover*	36 3/8 in. by 12 1/4 in.

Two gaskets were tested. One was a Chomerics** part number 10-07-3522-1405 radio-frequency interference (RFI) strip gasket. Two strips of this gasket material were used around the perimeter of the junction box, one on each side of the cover-attaching bolts. The other gasket tested was a Metex part number 01-0604-3856, "combo strip" RFI dual-strip gasket with adhesive backing, ferrex-material edges, and neoprene-sponge center, 1/8-in. thick and 3/4-in. wide with a 1/4-in. center strip. Figure 4 shows this gasket installed on the test-panel mating surface.

In addition to the tests on combinations of the three covers with and without the two gaskets, tests were also performed using Eccoshield PST-C-A 3-mil by 2-in. aluminum-foil, pressure-sensitive tape† over the cover bolts holding the flat plate cover in place (Figures 7 and 8)--both with and without the Metex gasket installed. Tests were performed with a 1 1/2-in. steel channel installed over the flat cover (Figure 9), also with and without a Metex gasket installed. Additional tests were then conducted with the mating surfaces painted with a heavy coat of white enamel (Contract #8010-079-3672, Federal Specification TT-E-00488), again with and without the Metex gasket.

Following these test results, the flat cover and junction box were modified so that 48 equally spaced cover bolts could be used, rather than 24 cover bolts as originally tested. This configuration was tested on both with and without the Metex gasket.

For all tests, the mating surfaces of each cover and the test panel were wire-brushed prior to testing (where appropriate) and the cover bolts were each tightened to approximately 10 ft-lb of torque.

---

* Both wrap-around covers had a lip which extended 5/8 in. around the edge of the box.

** Marketed by Chomerics, Inc., Woburn, MA.

† Marketed by Emerson & Cuming, Inc., Canton, MA.

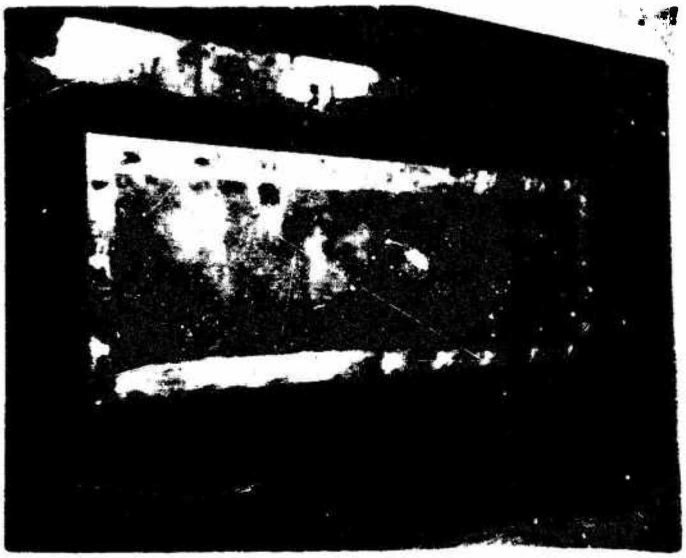


Figure 7. Eccoshield aluminum-foil tape on junction-box cover.

Figure 8. Eccoshield aluminum-foil tape on junction-box cover showing tape wrapped around edge.

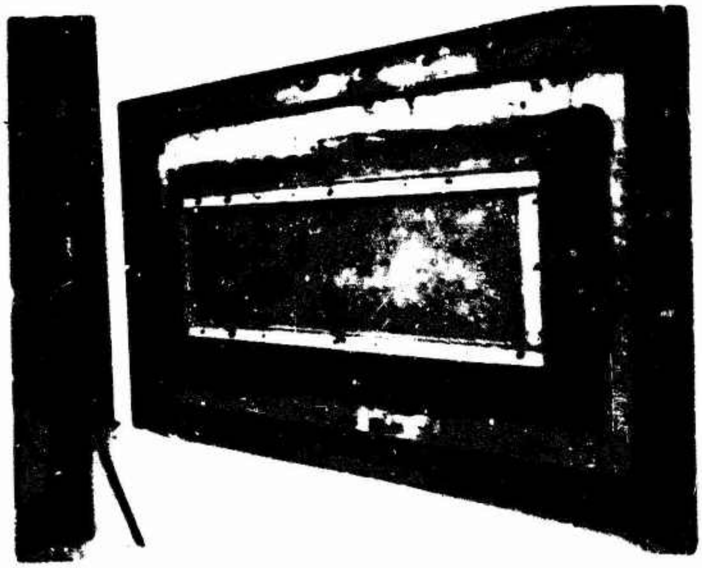


Figure 9. Flat cover with channel iron pressure plates mounted on shielded room wall.

Tests were also performed to investigate the relative shielding effectiveness of a 12-in. by 18-in. by 4 1/4-in. spot-welded, 16-gauge, steel junction box with a bolt-on cover. This junction box was built to SAFEGUARD specifications and was purchased from the Lee Products Co., Everett, MA. The cover mated with a 1/2-in. lip or flange that extended around the inside of the perimeter of the box. The cover was held in place with 12 1/4-in., #10 32 thread/in. screws approximately evenly spaced around the perimeter of the box.

Two test fixtures were manufactured. For one, the top 3 in. of the junction box were cut off and welded to a steel test panel that had an appropriate size opening cut in it. For the other, the remaining bottom portion of the box was welded to a similar steel test panel (Figure 10). Each panel was then connected to the access port in the wall of a shielded enclosure. During tests using the test fixture with the top portion of the box, the cover was installed as it would be on a junction box in the field. This fixture was tested with and without its cover. The bottom of the junction box was tested with no modifications and with the seams taped with Eccoshield 7PST-C-A 3-mil by 2-in. aluminum pressure-sensitive tape (Figure 11). When bolts were used they were tightened to approximately 10 ft-lb of torque.

Another 12-in. by 18-in. by 4 1/4-in. spot-welded, 16-gauge steel junction box (similar to the one described above) was constructed for doing injected current pulse testing. Two sections of 1-in. rigid-wall conduit were connected to each end of the junction box using 1-in.

Figure 10. Bottom of spot-welded junction box mounted on shielded enclosure (without conductive tape).

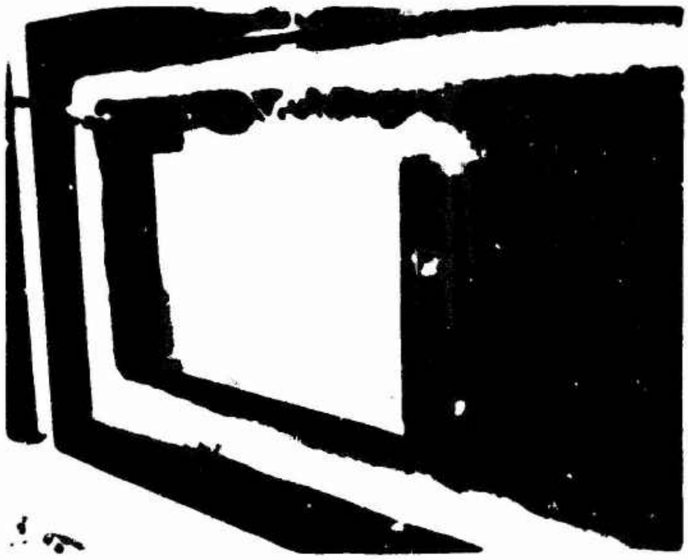


Figure 11. Bottom of spot-welded junction box (with conductive tape).

threaded hubs (Figure 12). The 1-in. conduits were cut so that the whole test sample was 10 ft long with the junction box at its center.

Data were taken with the cover installed, with and without a Technit* gasket (Figure 12). In addition, data were taken with a length of 3/4-in. wide, tinned copper braid passing along the top side of (and electrically in parallel with) the junction box (Figure 13), and again with a second strap across the cover of the junction box (Figure 14). In both cases, the braid was tightly stretched and was securely clamped to the conduit on either side of the junction box using automotive stainless-steel, screw-type hose clamps. The junction box and cover were then modified to accept 24 cover bolts (rather than 12 as in the original configuration) approximately equally spaced around the perimeter of the cover (Figure 15). Data were taken using the junction box as modified, without a gasket, in both the vertical and horizontal orientations.

<u>Measuring Techniques</u>. For the CW tests, the shielding effectiveness of each cover and gasket arrangement was indirectly measured using the techniques described in MILSTD-285 and IEEE Standard 299 (with the test panels described above mounted in one wall).[7] In general terms, this involved radiating the wall of the enclosure that contained the test fixture with CW signals of certain specified frequencies, and using a receiver located on the opposite side** of this wall to measure the power level, P_a, of the transmitted signal, after attenuation by the test sample (Figure 16). Also at each frequency, a reference power level, P_r, was obtained by measuring the above transmitted signal with nothing between the two antennas. Extreme care was taken to insure that the frequency, antenna spacing, and relative antenna orientations were the same for the measurement of both P_a and P_r.

The shielding effectiveness, SE, of a test sample at a specified

---

[7] *Recommended Practice for Measurement of Shielding Effectiveness of High-Performance Shielding Enclosures*, IEEE Standard 299 (Institute of Electrical and Electronics Engineers, Inc., 1969); *Method of Military Standard Attenuation Measurements for Electromagnetic Shielding of Enclosures Used for Electronic Test Purposes*, MIL-STD-285 (Department of Defense, June 1956).

* Technit part number 20-4G_#6, Sn Cu Fe shielding strip gasket with rectangular cross section (7/8 in. wide by 1/8 in. thick), marketed by Technical Wire Products, Inc.

** The transmitting antenna was inside the enclosure during tests of the small all-welded box fixture, but the receiving antenna was inside the enclosure for the remaining tests. The location of each was determined on the basis of convenience and should have had no effect on the resulting data.

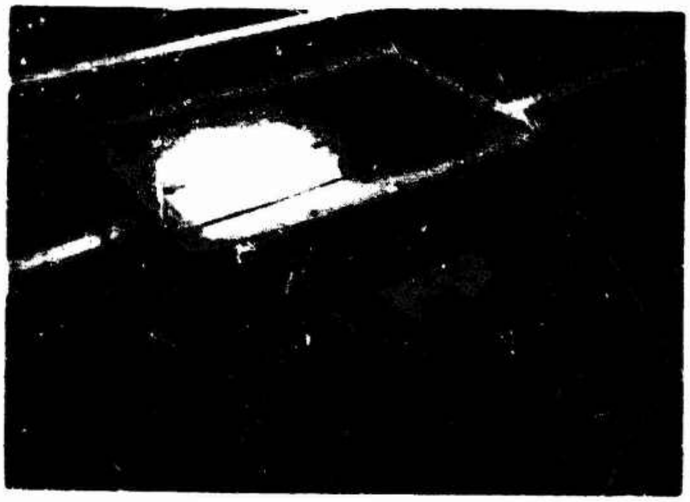


Figure 12. Technit gasket installed on junction box.

Figure 13. Junction box with copper braid in parallel.

Figure 14. Junction box with two copper braids in parallel.

Figure 15. Junction box with doubled number of cover bolts.

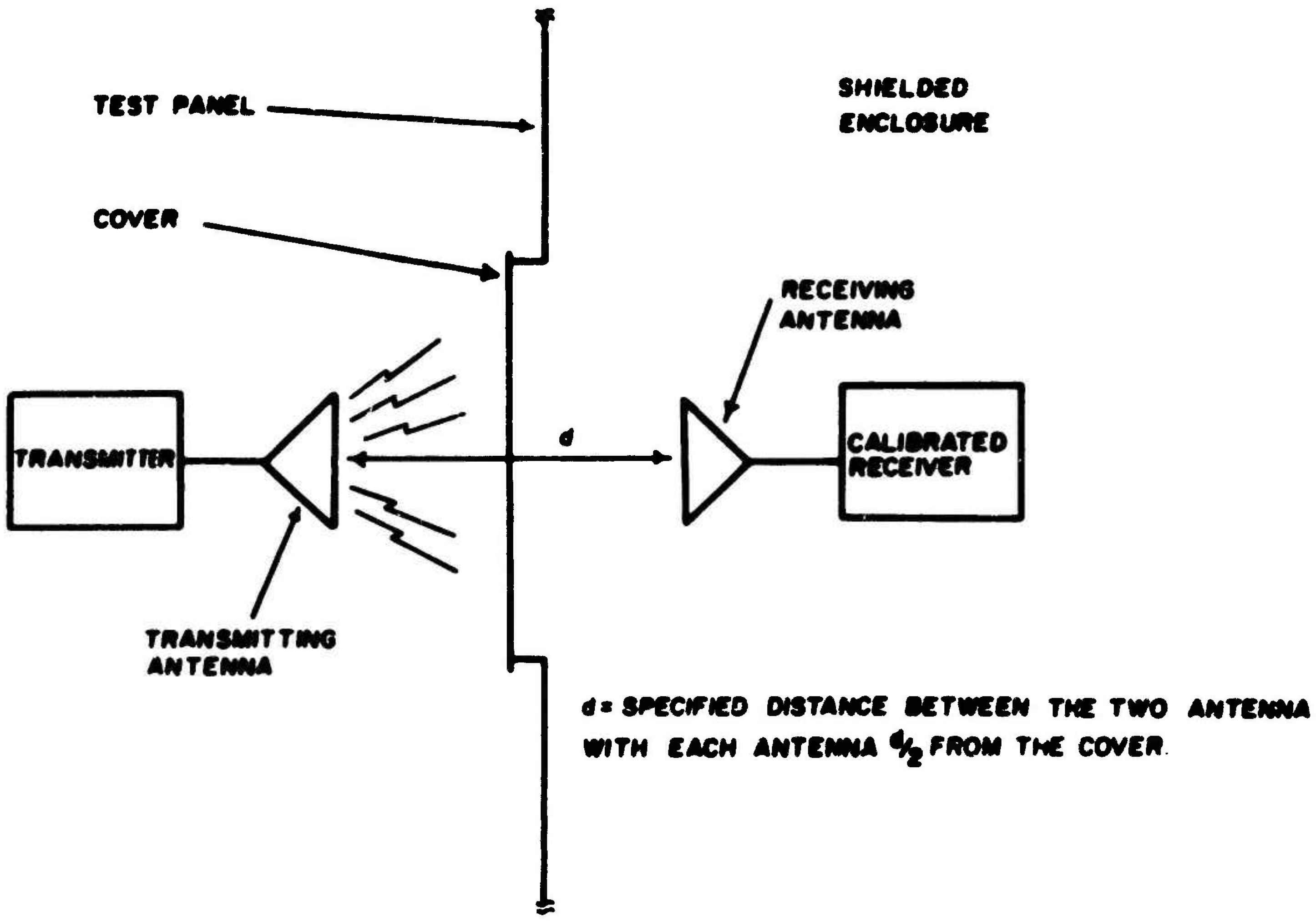


Figure 16. Test setup for CW testing of junction boxes.

frequency could then be found from

$$SE(dB) = 10 \log_{10} \frac{P_r}{P_a} . \qquad [Eq\ 1]$$

The easiest method for obtaining P_r and P_a was to place an attenuator between the receiver and the receiving antenna. Then, by adjusting the attenuator to get the same receiver reading for both P_a and P_r, the values of P_r and P_a relative to some base power level could be obtained. Since only the relative values of P_r and P_a are needed in Eq 1, the shielding effectiveness can be calculated without regard to receiver calibration. Thus, only the attenuator needs to be calibrated. Since most attenuators are calibrated in dB, the shielding effectiveness can be found directly from the attenuator settings by simply subtracting the attenuator setting for P_a from that for P_r.

The level of ambient noise* at each specific frequency of interest was also recorded. For maximum accuracy of test data, it is desirable to maintain the dynamic range of signal levels so that the minimum signal level received under any test condition (i.e., minimum value of P_a) is at least 10 dB greater than the ambient noise level at that frequency. However, when this is not possible, the resulting data can be adjusted to a more correct value by using the appropriate correction factor from the graph shown in Figure 17.

The separation between the two antennas for each test frequency was as follows:

10 kHz	2 ft (0.61 m)	30 MHz	2 ft (0.61 m)
40 kHz	2 ft (0.61 m)	500 MHz	6.56 ft (2 m)
200 kHz	2 ft (0.61 m)	2.5 GHz	6.56 ft (2 m)
1 MHz	2 ft (0.61 m)		

For the injected current pulse test, the 12-in. by 18-in. by 4 1/4-in. spot-welded, 16-gauge steel junction box described above was subjected to an electromagnetic pulse (EMP) as an alternative method of measuring its shielding effectiveness. The junction box containing the two sections of 1-in. rigid steel conduit was used as part of a parallel conduit transmission line (Figure 18). To minimize reflections, the transmission line was terminated with a resistor equal to the characteristic impedance (Z_0) of the transmission line (approximately 200 ohms).

The transmission line was driven by a Physics International FRP-50 pulser** that produced a 5-ns rise time, 150-amp, peak current pulse on

* This is the indicated signal level shown by the calibrated receiver when the transmitter is turned off.

** Marketed by Physics International Co., San Leandro, CA.

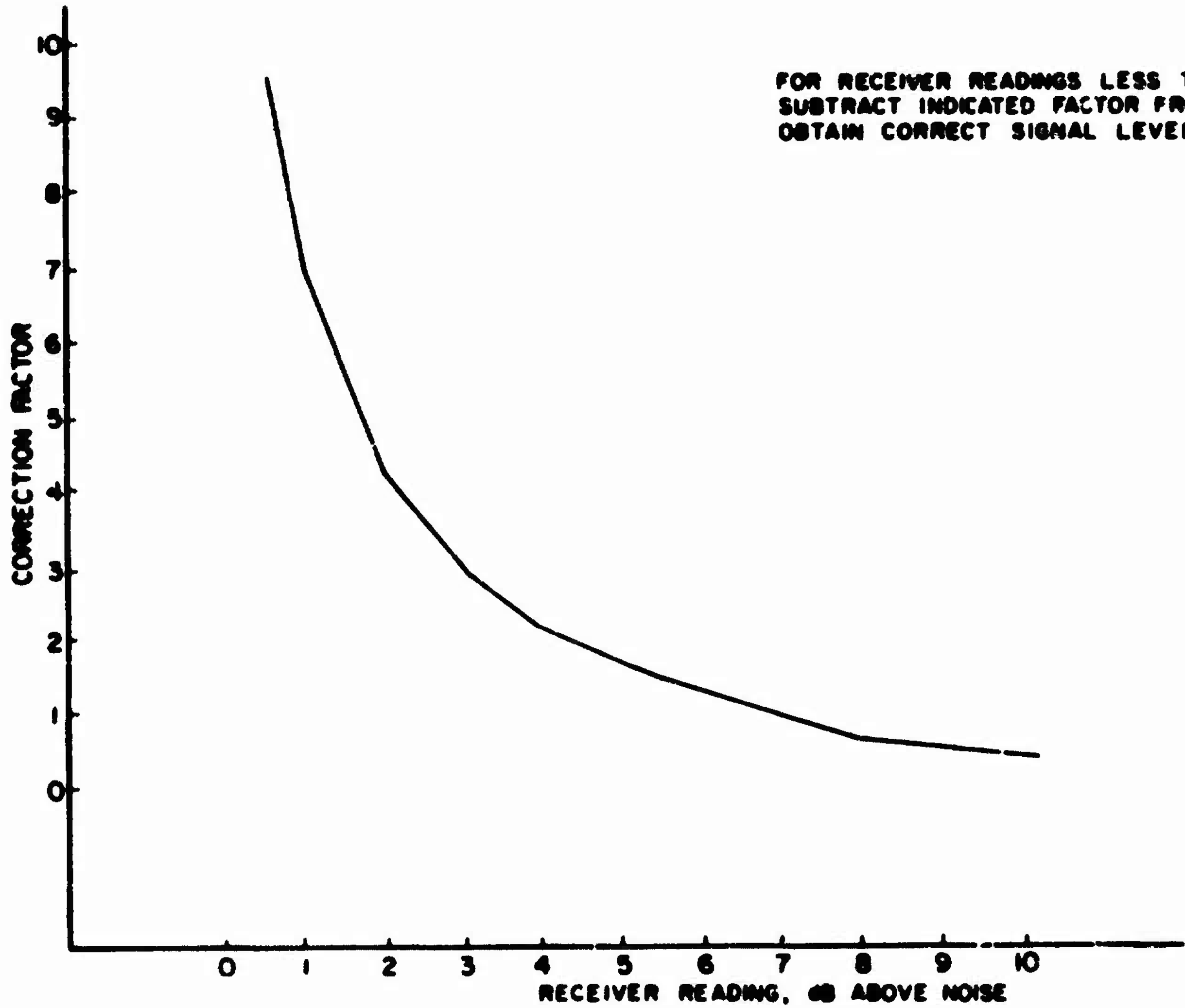


Figure 1'. Correction factor for low signal levels during CW tests.

the transmission line. The pulser uses a spark gap to discharge a capacitor into the line, producing a pulse with a decay constant of 4 microseconds.[3]

The conduit assembly containing the junction box constituted the ground side of the transmission line. This assembly extended a few inches beyond the terminating resistor and was coupled with reducers to a 4-in. I.D. conduit stub that had been inserted through, and welded to, a test panel connected to the access port of a shielded chamber (Figure 19). A #12 copper wire, referred to as a sense wire, was connected to the end cap of the conduit containing the junction box, and extended through the inside of this conduit, passing through the junction box and into the shielded chamber where the wire was grounded to the chamber wall. An oscilloscope and a current probe were used inside the shielded room to measure the current induced in the sense wire (I_{SC}) by the current pulse that was injected into the transmission line. Prior tests at CERL[4] have shown that an assembly consisting of properly installed hubs and conduit sections that have been properly joined provides sufficient EMP shielding to reduce the signal induced in the sense wire to a level that is too small to measure. Thus, it can be assumed that any signal that was detected on the sense wire was the result of the shielding degradation caused by the spot-welded junction box. The smaller the value of I_{SC}, the greater the shielding effectiveness of the junction box.

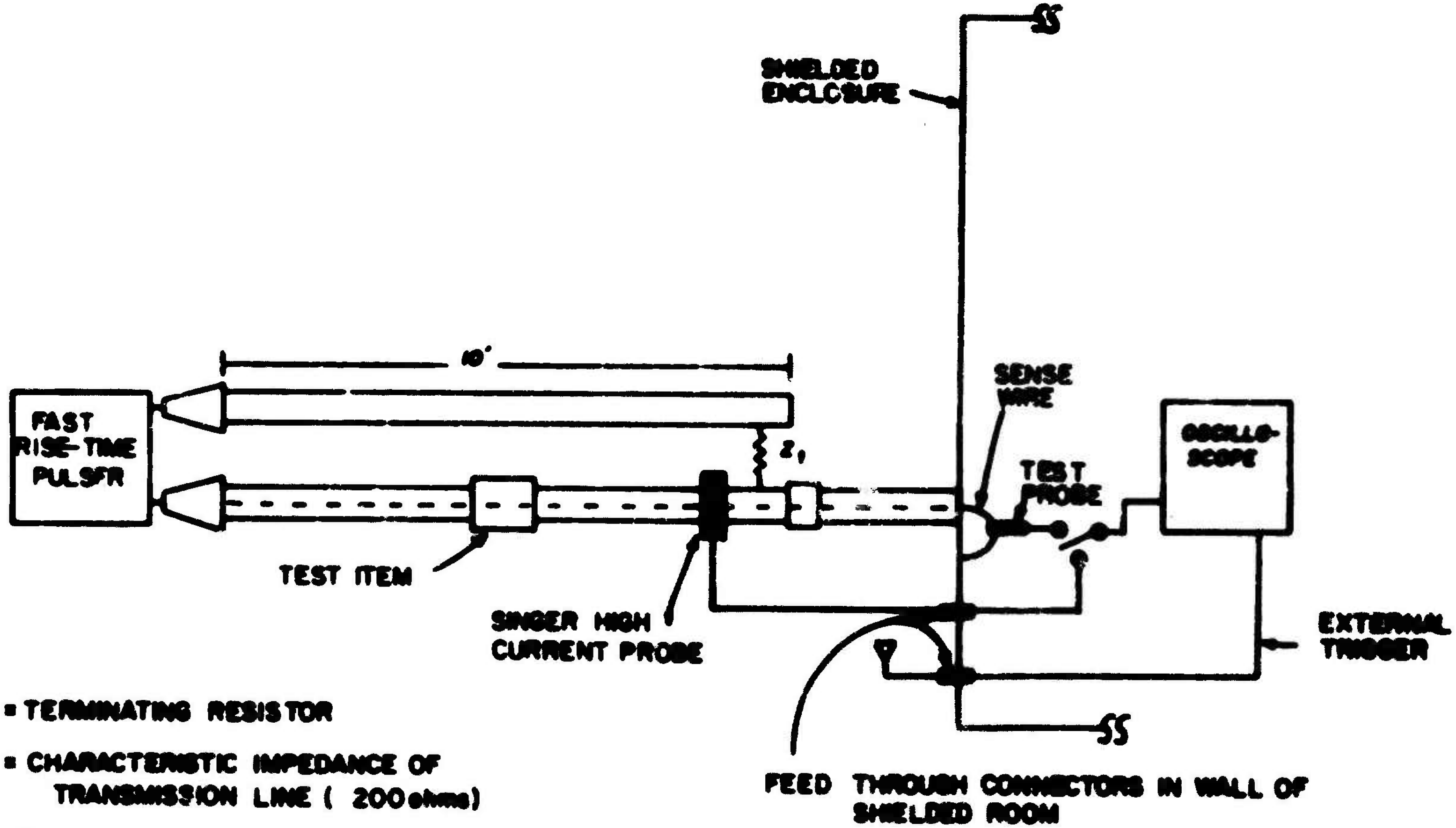
Tests were conducted with the junction box oriented so that the cover was vertical and on the side nearest the other conduit (Figure 19). The junction box rotated 90°, so that the cover was horizontal and on top of the box (Figure 20).

3 INSTRUMENTATION

Shielded Enclosure. Although two shielded enclosures were used during these tests, both were made of 11-gauge steel with all-welded construction and RFI-tight doors, and all had appropriate test ports for mounting the test panels described in Chapter 2. Both shielding enclosures provided at least 120 dB of shielding effectiveness over the frequency range from

[3] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *The Effect of Conduit Coupling Conditions on the EMP Shielding of Conduit Joints*, Letter Report E-4 (Construction Engineering Research Laboratory (CERL, July 1972); Leverenz, McCormack, and Nielsen, *EMP Shielding Properties of Conduit Systems and Related Hardware* [draft], (CERL, November 1974).

[4] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *EMP Evaluations of Conduit System Related Items*, Letter Report E-44 (CERL, April 1973); Leverenz, McCormack, and Nielsen, *EMP Shielding Properties of Conduit Systems and Related Hardware*.



Z_t = TERMINATING RESISTOR

Z_0 = CHARACTERISTIC IMPEDANCE OF TRANSMISSION LINE (200 ohms)

$Z_t = Z_0$

Figure 18. Test setup for injected current pulse testing of junction boxes.

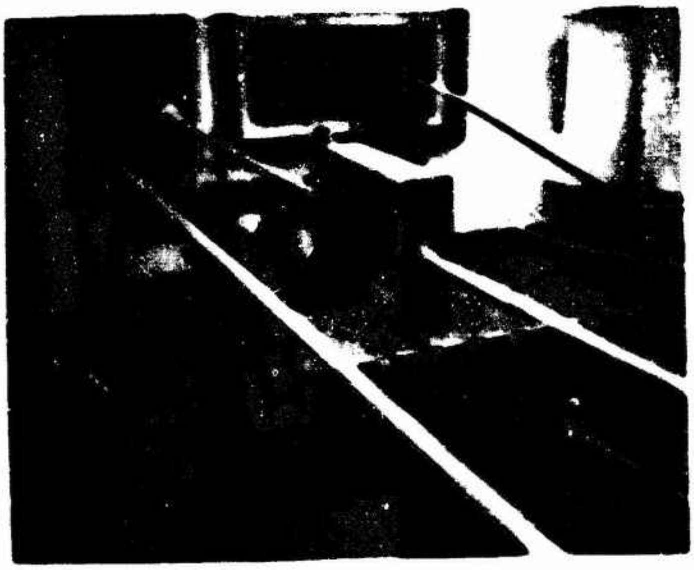


Figure 19. Spot-welded junction box installed in parallel conduit transmission line (box vertical).

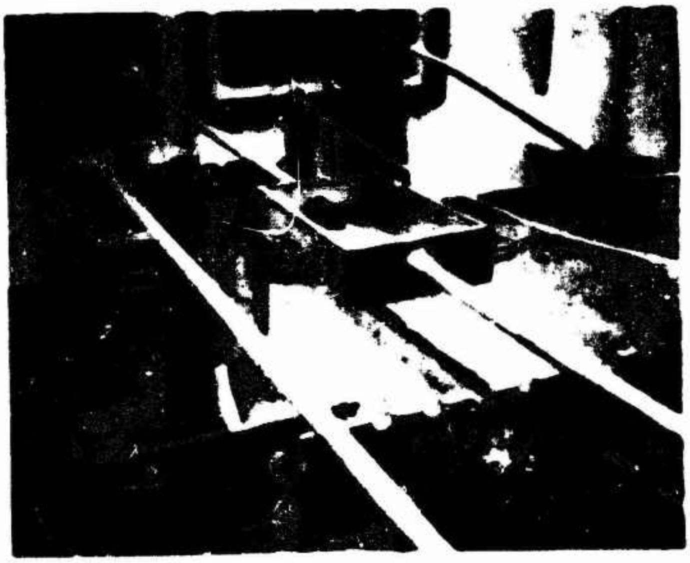


Figure 20. Spot-welded junction box installed in parallel conduit transmission line (box horizontal).

10 kHz to 10 GHz (when an 11-gauge steel panel was mounted on the test port).

CW Test Equipment. The following test equipment was used to transmit the various test signals at the indicated test frequencies: 10 kHz and 40 kHz (Figure 21):

a. Hewlett-Packard model 202D Audio Oscillator

b. M. B. Electronics model 2120D, 125VA power amplifier

c. CERL loop antenna (eight turns).

200 kHz, 1 MHz, and 30 MHz (Figure 22):

a. Hewlett-Packard model 606A signal generator

b. Electronic Navigation Industries model 310L, RF power amplifier

c. CERL loop antenna.

500 MHz and 2.5 GHz (Figure 23):

a. W. L. Maxon Corp. model 1141A UHF wide-band power oscillator

b. W. L. Maxon Corp. model 1141B power supply and modulator

c. PRD Electronics type 1211 isolator (2.5 GHz only)

d. Dipole antenna (500 MHz only)

e. DeMornay Bonardi model L-520 wave-guide horn antenna (2.5 GHz only).

The following test equipment, shown in Figure 24, was used to detect the transmitted CW signals at the indicated frequencies:

a. Stoddard Electro-Systems model NM-12AT, radio-frequency and field-intensity meter (10 kHz, 40 kHz, and 200 kHz).

b. Empire Devices Products Corp., model NF-105 noise and field-intensity meter, with

(1) TA/NF-105 tuning unit (1 MHz)

(2) T-1/NF-105 tuning unit (30 MHz)

(3) T-3/NF-105 tuning unit (500 MHz).

c. Empire Devices Products Corp., model NF-112, noise and field-

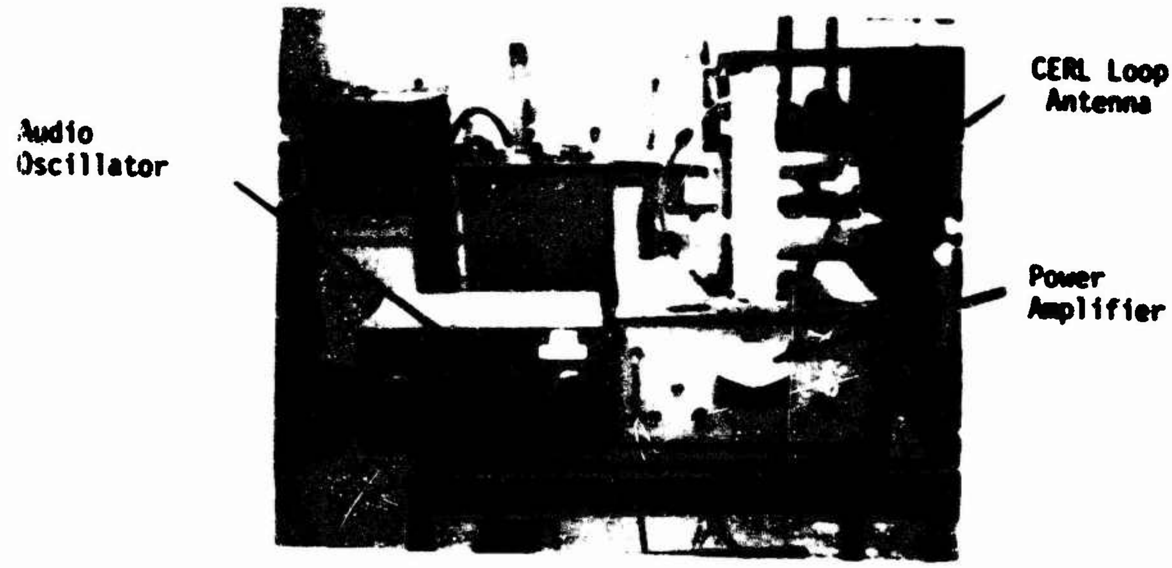


Figure 21. Transmitting equipment--10 kHz and 40 kHz

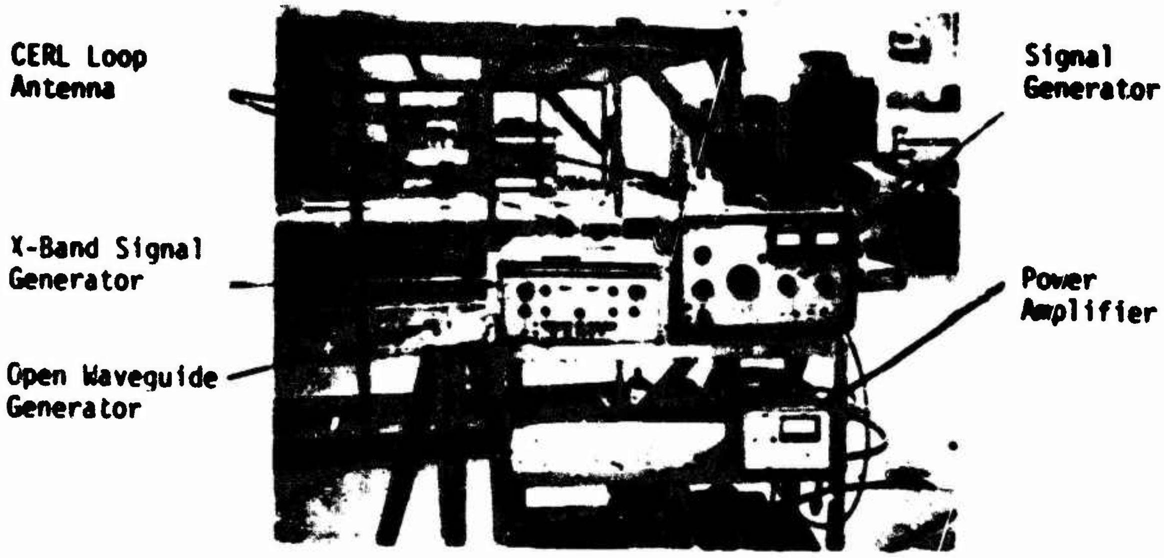


Figure 22. Transmitting equipment--200 kHz, 1 MHz, and 30 MHz.

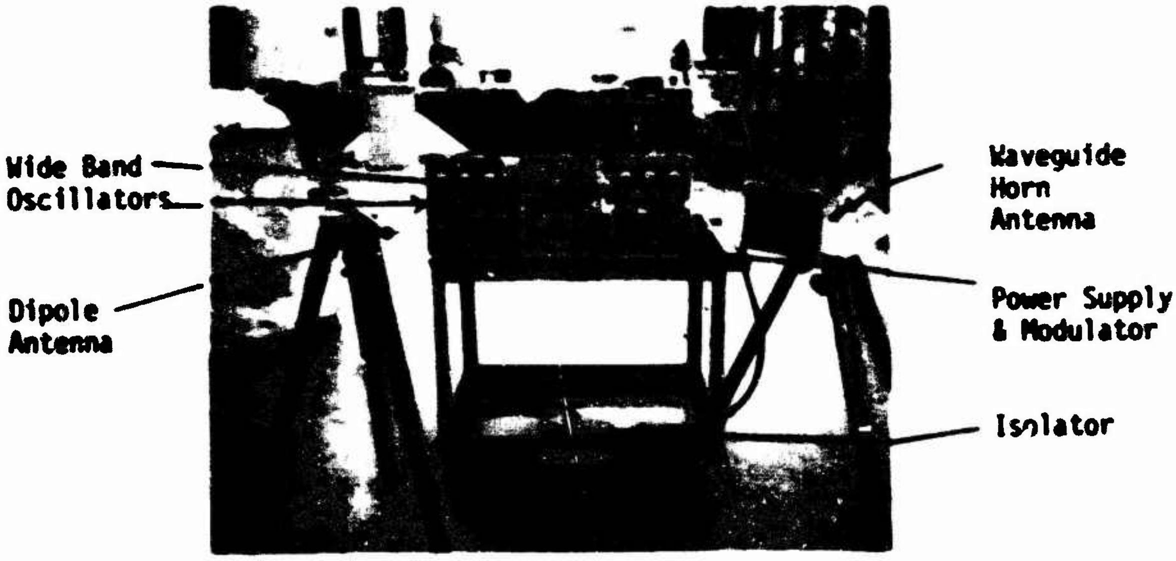


Figure 23. Transmitting equipment-- 500 kHz and 2.5 GHz.

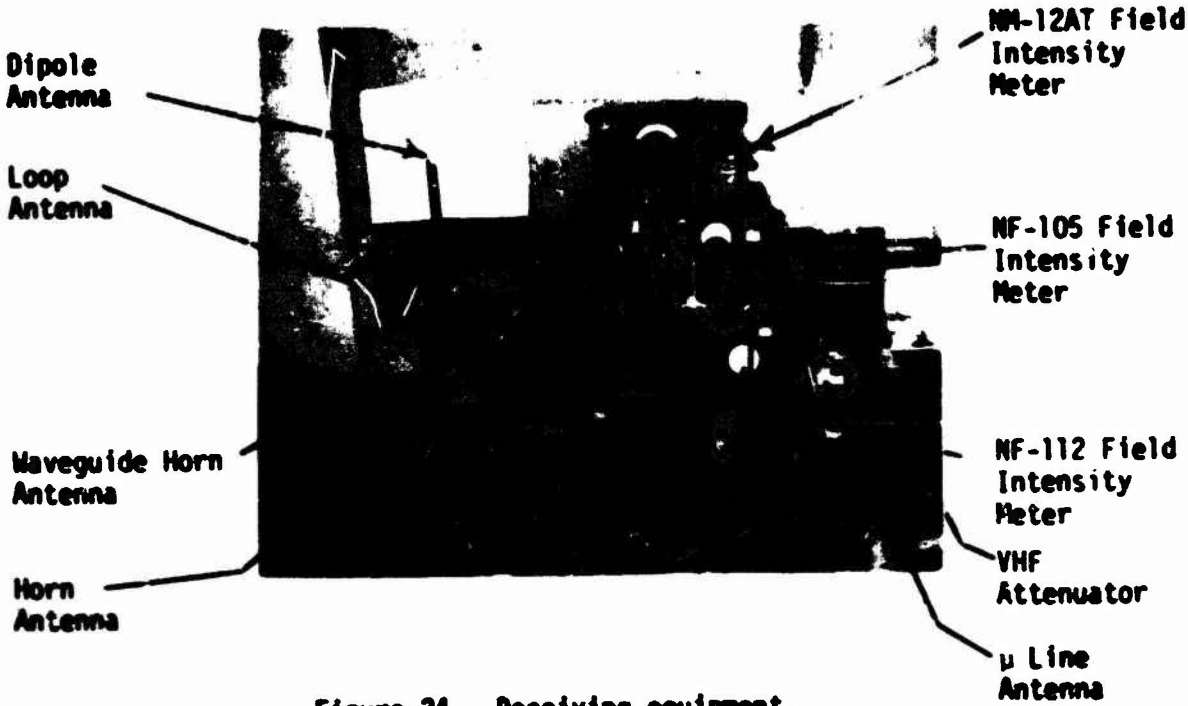


Figure 24. Receiving equipment.

intensity meter with T-2/NF-112 tuning units (2.5 GHz), (Polarad FIM-2 receiver used instead for the small junction-box tests only).

d. Hewlett-Packard model 335D VHG attenuator.

e. Arra, Inc., model 4-5414-30 line attenuator.

f. Dipole antenna (500 MHz).

g. Singer Co., Empire model LP-105 loop antenna (10 kHz, 40 kHz, 200 kHz, 1 MHz, and 30 MHz).

h. DeMornay Bonardi model L-520 wave-guide horn antenna (2.5 GHz).

Pulse Test Equipment. The pulser used was a Physics International model FRP-50. This pulser uses a low-inductance, cylindrically shaped 0.02-μf capacitor and an adjustable spark gap mounted coaxially inside a cylindrical chamber. The chamber is air tight and is pressurized with sulphur-hexafluoride (SF_6) gas. The desired firing voltage of the pulser is a function of the pressure of the SF_6 and the distance between the electrodes of the spark gap. A variable high-voltage D.C. power supply (up to 50 kV D.C.) supplies the firing voltage to the pulser.

When the spark gap fires, the capacitor is discharged into the pulser load (in this case, the parallel conduit transmission line), and the capacitor begins to recharge. The pulser is free running, with a repetition rate controlled by the amount the D.C. power supply exceeds the spark-gap firing voltage.

During the pulse tests reported herein, the pulser was adjusted to provide a peak current pulse (I_p) of approximately 150 amps. The high-voltage D.C. power supply was then adjusted to provide a repetition rate of approximately 1 pulse every 2 or 3 sec. The resulting pulse had a rise time (time for the signal to reach 90 percent of its peak value) of 3 ns, and a fall time (time for the signal to go from its peak value to 1/e times the peak value) of about 4 μsec.

The signal induced on the sense wire was recorded using a Tektronix C31 camera mounted on a Tektronix 454 oscilloscope. The A.C. current wave forms induced on the sense wire were detected using a Tektronix P6021 A.C. current probe and a type 134 amplifier. Laboratory checks of this probe arrangement verified that the frequency response was within the manufacturer's specifications (3 dB points at 120 Hz and 36 MHz). A Singer* model #95214-3 clamp-on current probe was used to measure the wave form of the current pulse injected into the transmission line by the pulser.

* Singer Instrumentation, Los Angeles, CA.

4 TEST RESULTS

CW Tests. Results of CW tests on the small, all-welded junction box are given in Appendix A and are summarized in Table 1. As shown, none of the commercially available RFI gasket materials significantly improved the shielding effectiveness of the junction box (as compared to the junction box without a gasket). The steel-wool gasket was the only gasket tested that appreciably improved the shielding effectiveness of this junction box.

Results of CW tests on the large, all-welded junction box are given in Appendix B and are summarized in Table 2. Note that some tests were performed more than once using the same test configuration and the same material. These test results are identified by a digit corresponding to the order in which they were conducted and give a measure of the repeatability of the test data.

As shown in Table 2, the configurations that used the Metex gasket, with the exception of the configuration that had the mating surfaces painted prior to testing, resulted in the most appreciable increase in shielding effectiveness--with the maximum shielding effectiveness being achieved using the flat cover with 48 cover screws and the Metex gasket.

It should be noted that though the tight-fitting, wrap-around cover without a gasket did provide some improvement in shielding effectiveness (over the flat cover without a gasket), the loose-fitting cover without a gasket provided little or no improvement. Thus, apparently a tight fit is necessary to provide a significant improvement in shielding characteristics (in this case the cover was driven on with a mallet).

Results of the tests with paint on the mating surfaces verify that the shielding effectiveness of the all-welded, steel junction box and cover combination is dependent on the degree of good electrical contact between the cover and the junction-box mating surface around the entire perimeter.

Results of CW tests on the spot-welded junction box are given in Appendix C and are summarized in Tables 3(a) and 3(b). From these results, it is obvious that the major source of leakage for spot-welded junction boxes is around the cover of the box. Likewise, comparison between Tables 2 and 3(b) shows that the spot-welded box itself provides better shielding than any cover-gasket combination, except at the highest frequencies. At high frequencies, some increase in the high-frequency shielding can be obtained if the seams are taped with Ecco-shield 7 PST-C-A aluminum-foil, pressure-sensitive tape. Finally, comparing Tables 2 and 3(a) shows that the performance of all-welded and spot-welded boxes with flat covers and no gaskets is essentially the same. The effects of spot-welded seams are only seen with extremely good covers and then only at high frequencies.

Table 1

Summary of CW Test Results--Small All-Welded 11-Gauge Steel Junction Box

Frequency	No cover* SE (dB)	Rubber gasket SE (dB)	No gasket SE (dB)	Steel-wool gasket SE (dB)	Elastomet gasket SE (dB)	Xecon gasket	1/8 in. Xecon SE (dB)
10 kHz	42 - 45	49	55	58	53		
40 kHz	42 - 46	52	61	67	60		
200 kHz	42	54	65	83	57	62	58
1 MHz	44	66	87	102.5	67	66	61.5
30 MHz	39 - 48	63	81	>125	95	97.5	74
450 MHz	43 - 51	70	104	>133	104		
1 GHz	20 - 24	35	73	>111	76		
2.5 GHz	2 - 20	57	52	> 86	38	87.5	62

* Measurements made with cover removed to investigate signal level with the hole on the test panel open.

NOTE: More than one value for any test condition above indicates that more than one test was performed under those conditions.

Table 2

Summary of CW Test Results--Large All-Welded 11-Gauge Steel Junction Box

Test Configuration	10 kHz	40 kHz	200 kHz	1 MHz	30 MHz	500 MHz	2.5 GHz
Flat Plate Cover							
1. No gasket #1	47	53.5	60.5	69	83.5	75	77
2. No gasket #2	42.5	50	57	62.5	78	82	55.5
3. No gasket #3	40.5	47.5	57	60	77	90	56
4. Chomerics gasket	34.5	40	50	54	65.5	97	100
5. Metex gasket #1	51	64	78	98	>120*	>131*	>125*
6. Metex gasket #2	54	66.5	81	101*	>118*	>138*	123*
7. Eccoshield tape	46	59	68	78	90.5	116	81
8. Metex gasket and Eccoshield tape	55.5	68	83	109.3*	>118*	>128*	>125*
9. 1 1/2" channel iron	50	58	66	73.5	93.5	106	70
10. 1 1/2" channel iron* Metex gasket	57	71	89	>120*	>127	>135	>125*
11. W/paint	35	42	46	54	73	89	55
12. W/paint & Metex gasket	41	50	58	74	103	119	81
13. W/48 cover screws	70	77.5	84	95.5	113.2*	112	76
14. W/48 cover screws & Metex gasket	98	126.7*	>126.5*	>121*	>124*	>133*	>125
Tight-Fit Wrap-Around Cover							
15. No gasket #1	50	58	71	74	89	103.5*	60.5
16. No gasket #2	54	62.5	69	72.5	90.5	104	56.5
17. Metex gasket #1	61.5	77	92	>113*	>114	>134	>127*
18. Metex gasket #2	64.5	77.5	93	>116*	>118*	>138*	>124*
Loose-Fit Wrap-Around Cover							
19. No gasket	46	53	71	68	83.5	85	64

* Data points corrected using correction factor for low-level signals (Figure 17) at a particular frequency because there were less than 10 dB between received signal and ambient noise.

Pulse Tests. Results of the injected current pulse tests are shown in Table 4. The variation between the different configurations is small, probably due to the fact that most of the leakage is through the spot-welded seams. This is to be expected, since the injected current pulse contains mostly high-frequency components (which, from the radiated CW measurements, is where the spot-welded seams were shown to leak).

Table 3

Summary of CW Test Results

(a) Cover lid portion, spot-welded 16-gauge steel junction box.

Frequency	SE(dB)	
	Without Cover	With Cover
10 kHz	12.5	46
40 kHz	12	52
200 kHz	16	61.5
1 MHz	8.5	70
30 MHz	15	96.5
500 MHz	8	74
2.5 GHz	1	46

(b) Bottom portion of spot-welded 16-gauge steel junction box, with and without Eccoshield ? PST-C-A 3-mil by 2-in. aluminum pressure-sensitive tape applied over seams.

Frequency	SE(dB)	
	Without Tape	With Tape
10 kHz	91	93
40 kHz	100	100
200 kHz	105	105
1 MHz	>105	>109
30 MHz	>116	>115
500 MHz	78	96
2.5 GHz	69	85

Table 4

Pulse Test Results--Spot-Welded 16-Gauge Steel Junction Box

Orientation	Configuration	Peak I_{sc} (mA)
Cover Vertical	No gasket	40
Cover Vertical	No gasket + 1 braid	42
Cover Vertical	No gasket + 2 braids	20
Cover Horizontal	No gasket	60
Cover Horizontal	With gasket	75
Cover Vertical	With gasket	30
Cover Vertical	24 screws - no gasket	36
Cover Horizontal	24 screws - no gasket	35

NOTE: In all configurations, the peak I_{sc} occurred approximately 5 μsec after the pulser fired. A minor second peak, 4 to 9 mA in magnitude, occurred 2 to 8 μsec after the pulser fired.

5 SUMMARY

Conclusions. Steel wool was the only gasket material tested with the small box that significantly improved the shielding effectiveness of the junction box. The conductive rubber gaskets showed mixed results, but generally offered slightly improved shielding over the plain rubber gasket.

The addition of a metal lip around the periphery of the cover offered some improvement in shielding effectiveness; however, the additional fabrication costs are probably not justified in that the same or better results are possible with plain covers and good gaskets.

The Metex gasket ("combo strip," dual-strip RFI gasket) produced the most improvement in shielding effectiveness. Doubling the number of cover bolts in conjunction with the Metex gasket produced the largest increase in shielding effectiveness.

Tests indicated that most of the leakage for the spot-welded junction box occurs at the box-cover interface. It was therefore concluded that the results obtained from testing the all-welded boxes could be directly applied to spot-welded boxes.

Recommendations. Based on the tests conducted, the following gasket/-junction-box configurations were found to meet the SAFEGUARD shielded liner specifications (80 dB attenuation from 200 kHz to 2.5 GHz):

a. Steel-wool gasket

b. Flat cover with Metex gasket

c. Flat cover with Metex gasket and Eccoshield tape

d. Flat cover with Metex gasket and channel iron pressure plates

e. Flat cover with 48 cover bolts (no gasket)

f. Flat cover with 48 cover bolts and Metex gasket.

Where improvement of shielding effectiveness over the existing installations is required, it is recommended that the number of cover bolts be increased. This appears to be the easiest method of obtaining a significant improvement in shielding effectiveness. If additional improvement is necessary, the Metex "combo strip" gasket can be used, along with an increase in the number of cover bolts.

The Metex gasket can also be used where a weatherproof seal is required. Conductive rubber gaskets appear to provide only a small improvement over ordinary rubber gaskets and should only be used where required for weatherproofing.

Although steel wool provided an increase in shielding effectiveness, its use is not recommended due to difficulties in forming and placing and its susceptibility to deterioration.

APPENDIX A:

DATA OBTAINED DURING CW TESTS OF THE SMALL, ALL-WELDED, 11-GAUGE STEEL JUNCTION BOX

Table A1

Test Data for Junction Box with No Cover (#1)

Frequency	P_R (dB)*	Noise (dB)	P_a (dB)**	SE(dB)
10 kHz	63	<- 40	21	42
40 kHz	67	<- 40	25	42
200 kHz	76	<- 40	34	42
1 MHz	115	4	71	44
30 MHz	126	10	87	39
450 MHz	118	- 6	75	43
1 GHz	96	- 6	76	20
2.5 GHz	97	20	87	10

Table A2

Test Data for Junction Box with No Cover (#2)

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	62	<- 40	17	45
40 kHz	68	<- 40	22	46
200 kHz	71	<- 40	29	42
1 MHz	111	3	67	44
30 MHz	114	9	66	48
450 MHz	115	2	64	51
1 GHz	102	6	78	24
2.5 GHz	110	36	108	2

* P_R = reference power level--with no shielding between antennas.

** P_a = attenuated power level--with test item between antennas.

Table A3

Test Data for Junction Box with Factory-Supplied Rubber Gasket

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	63	<- 40	14	49
40 kHz	67	<- 40	15	52
200 kHz	76	<- 40	22	54
1 MHz	115	4	49	66
30 MHz	126	10	63	63
450 MHz	118	- 6	48	70
1 GHz	96	- 6	61	35
2.5 GHz	98	20	41	57

Table A4

Test Data for Junction Box Cover with No Gasket

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	63	<- 40	8	55
40 kHz	67	<- 40	6	61
200 kHz	76	<- 40	11	65
1 MHz	115	4	28	37
30 MHz	126	10	45	81
450 MHz	118	- 6	14	104
1 GHz	96	- 6	23	73
2.5 GHz	97	20	45	52

Table A5

Test Data for Junction Box with Steel-Wool Gasket

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	63	<- 40	5	58
40 kHz	67	<- 40	0	67
200 kHz	76	<- 40	- 7	83
1 MHz	115	4	13 (-0.5dB cf)*	102.5
30 MHz	126	10	10 (-9dB cf)	>125
450 MHz	118	- 6	- 6 (-9dB cf)	>133
1 GHz	96	- 6	- 6 (-9dB cf)	>111
2.5 GHz	97	20	20 (-9dB cf)	> 86

Table A6

Test Data for Junction Box with Elastomet Gasket

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	62	<- 40	9	53
40 kHz	68	<- 40	8	60
200 kHz	71	<- 40	14	57
1 MHz	111	3	44	67
30 MHz	114	9	19	95
450 MHz	115	2	11	104
1 GHz	102	6	26	76
2.5 GHz	110	36	72	38

* A cf notation in these tables indicates that a correction factor from Figure 17 is applied to that data entry.

APPENDIX B:

DATA OBTAINED DURING CW TESTS OF THE LARGE, ALL-WELDED, 11-GAUGE STEEL JUNCTION BOX

Table B1

Test Data for Junction Box with Flat Plate Cover--No Gasket (#1)

Frequency	P_R (dB)	Noise (dB)	P_a(dB)	SE (dB)
10 kHz	79	<- 40	32	47
40 kHz	91	<- 40	37.5	53.5
200 kHz	76.5	<- 40	16	60.5
1 MHz	103	0	34	69
30 MHz	87.5	0	4	83.5
500 MHz	118	0	43	75
2.5 GHz*	130	30	53	77

* Antenna spacing was 4 m rather than 2 m normally used.

Table B2

Test Data for Junction Box with Flat Plate Cover--No Gasket (#2)

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	35.5	42.5
40 kHz	93	<- 40	43	50
200 kHz	76	<- 40	19	57
1 MHz	102	- 5	39.5	62.5
30 MHz	100	- 6	22	78
500 MHz	101	- 6	19	82
2.5 GHz	134	34.5	78.5	55.5

Table B3

Test Data for Junction Box with Flat Plate Cover--No Gasket (#3)

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	37.5	40.5
40 kHz	92.5	<- 40	45	47.5
200 kHz	76	<- 40	19	57
1 MHz	101	- 6	41	60
30 MHz	103	- 6	26	77
500 MHz	123	- 6	33	90
2.5 GHz	150	33	94	56

Table B4

Test Data for Junction Box with Flat Plate Cover with Chomerics Gasket

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	79	<- 40	44.5	34.5
40 kHz	91	<- 40	51	40
200 kHz	76.5	<- 40	26.5	50
1 MHz	103	0	49	54
30 MHz	87.5	0	22	65.5
500 MHz	118	0	21	97
2.5 GHz*	130	30	30	100

* Antenna spacing was 4 m rather than 2 m normally used.

Table B5

Test Data for Junction Box with Flat Plate Cover with Metex Gasket (#1)

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	27	51
40 kHz	94	<- 40	30	64
200 kHz	75	<- 40	- 2	78
1 MHz	104	- 6	6	98
30 MHz	105	- 6	- 6 (-9dB cf)	>120
500 MHz	116	- 6	- 6 (-9dB cf)	>131
2.5 GHz	150	34	34 (-9dB cf)	>125

Table B6

Test Data for Junction Box with Flat Plate Cover with Metex Gasket (#2)

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	79	<- 40	24	54
40 kHz	92.5	<- 40	26	66.5
200 kHz	76	<- 40	- 5	81
1 MHz	101	- 6	1 (-1dB cf)	101
30 MHz	103	- 6	- 6 (-9dB cf)	>118
500 MHz	123	- 6	-6 (-9dB cf)	>138
2.5 GHz	150	33	34 (-7dB cf)	>123

Table B7

Test Data for Junction Box with Flat Plate Cover with Ecoshield PST-C-A Tape

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	32	46
40 kHz	93	<- 40	34	59
200 kHz	77	<- 40	9	68
1 MHz	102	- 40	24	78
30 MHz	100	- 6	9.5	90.5
500 MHz	126	- 6	10	116
2.5 GHz	134	33.5	53	81

Table B8

Test Data for Junction Box with Flat Plate Cover with Metex Gasket and Eccoshield Tape

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	22.5	55.5
40 kHz	92.5	<- 40	24.5	68
200 kHz	76	<- 40	- 7	83
1 MHz	101	- 6	- 4 (-4.3dB cf)	109.3
30 MHz	103	- 6	- 6 (-9dB cf)	>118
500 MHz	123	- 6	- 6 (-9dB cf)	>128
2.5 GHz	150	34	34 (-9dB cf)	>125

Table B9

Test Data for Junction Box with Flat Plate Cover with 1 1/2-In. Channel Iron Stiffners

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	77	<- 40	27	50
40 kHz	92	<- 40	34	58
200 kHz	75	<- 40	- 9	66
1 MHz	105	- 6	31.5	73.5
30 MHz	112	- 6	18.5	93.5
500 MHz	120	- 6	14	106
2.5 GHz	150	34	80	70

Table B10

Test Data for Junction Box with Flat Plate Cover with 1 1/2-In. Channel Iron Stiffners and Metex Gasket

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	77	<- 40	20	57
40 kHz	92	<- 40	21	71
200 kHz	75	<- 40	- 14	89
1 MHz	105	- 6	- 6 (-9dB cf)	>120
30 MHz	112	- 6	- 6 (-9dB cf)	>127
500 MHz	120	- 6	- 6 (-9dB cf)	>135
2.5 GHz	150	34	34 (-9dB cf)	>125

Table B11

Test Data for Junction Box with Flat Plate Cover with Paint on Mating Surface

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	79	<- 40	43	35
40 kHz	93	<- 40	51	42
200 kHz	76	<- 40	30	46
1 MHz	105	- 6	51	54
30 MHz	108	- 6	35	73
500 MHz	120	- 6	31	89
2.5 GHz	151	34	96	55

Table B12

Test Data for Junction Box with Flat Plate Cover with Metex Gasket and Paint on Mating Surfaces

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	37	41
40 kHz	93	<- 40	43	50
200 kHz	76	<- 40	18	58
1 MHz	105	- 6	31	74
30 MHz	108	- 6	5	103
500 MHz	120	- 6	1	119
2.5 GHz	151	34	70	81

Table B13

Test Data for Junction Box with Tight-Fit, Wrap-Around Cover--No Gasket (#1)

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	28	50
40 kHz	93	<- 40	35	58
200 kHz	76	<- 40	5	71
1 MHz	102	- 5	28	74
30 MHz	100	- 6	11	89
500 MHz	101	- 6	- 1 (-1.5dB correction factor)	103.5
2.5 GHz	134	34.5	73.5	60.5

Table B14

Test Data for Junction Box with Tight-Fit, Wrap-Around Cover--No Gasket (#2)

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	2[illegible]	54
40 kHz	92.5	<- 40	30	62.5
200 kHz	76	<- 40	7	69
1 MHz	101	- 6	28.5	72.5
30 MHz	103	- 6	12.5	90.5
500 MHz	123	- 6	19	104
2.5 GHz	150	33	93.5	56.5

Table B15

Test Data for Junction Box with Tight-Fit, Wrap-Around Cover with Metex Gasket (#1)

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	16.5	61.5
40 kHz	94	<- 40	17	77
200 kHz	76	<- 40	- 16	92
1 MHz	104	- 6	- 6 (-9dB cf)	>113
30 MHz	99	- 6	- 6 (-9dB cf)	>114
500 MHz	119	- 6	- 6 (-9dB cf)	>134
2.5 GHz	151	33	33 (-9dB cf)	>127

Table B16

Test Data for Junction Box with Tight-Fit, Wrap-Around Cover with Metex Gasket (#2)

Frequency	P_R (dB)	Noise (db)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	13.5	64.5
40 kHz	92.5	<- 40	15	77.5
200 kHz	76	<- 40	- 17	93
1 MHz	101	- 6	- 6 (-9dB cf)	>116
30 MHz	103	- 6	- 6 (-9dB cf)	>118
500 MHz	123	- 6	- 6 (-9dB cf)	>138
2.5 GHz	150	33	34 (-9dB cf)	>124

Table B17

Test Data for Junction Box with Loose-Fit, Wrap-Around Cover--No Gasket

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	32	46
40 kHz	93	<- 40	29.5	53
200 kHz	76	<- 40	5	71
1 MHz	102	- 5	35	68
30 MHz	100	- 6	16.5	83.5
500 MHz	101	- 6	16	85

Table B18

Test Data for Junction Box with Flat Plate Cover with 48 Bolts

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	79	<- 40	9	70
40 kHz	93	<- 40	15.5	77.5
200 kHz	77.5	<- 40	- 6.5	84
1 MHz	106	- 6	10.5	95.5
30 MHz	109	- 6	- 2 (-2.2dB cf)	113.2
500 MHz	118	- 6	6	112
2.5 GHz	150	34	74	76

Table B19

Test Data for Junction Box with Flat Plate Cover with
48 Bolts and Metex Gasket

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	79	<- 40	- 18	98
40 kHz	94	<- 40	- 32 (-0.7dB cf)	126.7
200 kHz	77.5	<- 40	- 40 (-9dB cf)	>126.5
1 MHz	106	- 6	- 6 (-9dB cf)	>121
30 MHz	109	- 6	- 6 (-9dB cf)	>124
500 MHz	118	- 6	- 6 (-9 dB cf)	>133
2.5 GHz	150	34	34 (-9dB cf)	>125

APPENDIX C:

DATA OBTAINED DURING CW TESTS OF THE SPOT-WELDED, 16-GAUGE STEEL JUNCTION BOX

Table C1

Test Data for Junction Box with Cover Removed

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	65.5	12.5
40 kHz	91	<- 40	79	12
200 kHz	77.5	<- 40	61.5	16
1 MHz	99.5	1	91	8.5
30 MHz	103	- 4	88	15
500 MHz	102	- 6	94	8
2.5 GHz	136	30	135	1

Table C2

Test Data for Junction Box with Cover Installed

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	78	<- 40	32	46
40 kHz	91	<- 40	39	52
200 kHz	77.5	<- 40	16	61.5
1 MHz	99.5	1	29.5	70
30 MHz	103	- 4	6 (1/2dB cf)	96.5
500 MHz	102	- 6	28	74
2.5 GHz	136	30	90	46

Table C3

Test Data for Junction Box Without Aluminum-Foil Tape

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	75	<- 40	- 16	91
40 kHz	90	<- 40	- 10	100
200 kHz	74	<- 40	- 31	105
1 MHz	105	~ 0	~ 0	>105
30 MHz	116	~ 0	~ 0	>116
500 MHz	108	~ 0	30	78
2.5 GHz	109	~ 0	40	69
9.5 GHz	85	~ 0	27	58

Table C4

Test Data for Junction Box with Aluminum-Foil Tape

Frequency	P_R (dB)	Noise (dB)	P_a (dB)	SE (dB)
10 kHz	75	<- 40	- 18	93
40 kHz	90	<- 40	- 10	100
200 kHz	74	<- 40	- 31	105
1 MHz	109	~ 0	~ 0	>109
30 MHz	115	~ 0	~ 0	>115
500 MHz	106	~ 0	10	96
2.5 GHz	100	~ 0	15	85
9.5 GHz	86	~ 0	~ 0	>86

REFERENCES

Leverenz, D. J., R. G. McCormack, and P. H. Nielsen, *The Effect of Conduit Coupling Conditions on the EMP Shielding of Conduit Joints*, Letter Report E-4 (Construction Engineering Research Laboratory (CERL), July 1972).

Leverenz, D. J., R. G. McCormack, and P. H. Nielsen, *EMP Evaluations of Conduit System Related Items*, Letter Report E-44 (CERL, April 1973).

Leverenz, D. J., R. G. McCormack, and P. H. Nielsen, *HEMP Shielding Properties of Conduit Systems and Related Hardware* [draft], (CERL, November 1974).

Method of Military Standard Attenuation Measurements for Electromagnetic Shielding of Enclosures Used for Electronic Test Purposes, MIL-STD-285 (Department of Defense, June 1956).

Recommended Practices for Measurement of Shielding Effectiveness of High-Performance Shielding Enclosures, IEEE Standard 299 (Institute of Electrical and Electronics Engineers, Inc., 1969).